Kinematic Analysis of an Anthropomorphic Robot Hand

Pramod Kumar Parida[1, a], Bibhuti Bhusan Biswal[2,b] and Dhirendra Nath Thatoi[3,c]

[1]National Institute of Technology, Rourkela, Odisha, India

[2]National Institute of Technology, Rourkela, Odisha, India

[3]SOA University, Bhubaneswar, Odisha, India

[a]pramodparida71@yahoo.com, [b]bbbiswal@nitrkl.ac.in, [c]massthatoi@gmail.com

Keywords: robot hand, anthropomorphic, kinematic analysis, manipulation, simulation.

Abstract. There has been a continuous effort by researchers to develop multi-fingered robot hands for variety of applications. Some of these hands are meant for industrial applications while thers are used for orthopedic rehabilitation of humans. However the degree of success to develop an anthropomorphic robot hand in close resemblence with a typical human hand has not been satisfactory. In the present work an attempt has been made to design a robot hand having five fingers with 25 degrees of freedom by closly following the anatomy of human hand.The kinematic analysis of the hand offers confirmative results for effective graspingand manipulating objects.

Introduction

A robotic hand is one that can mimic the movements of human hand in operation.Stable grasping and fine manipulation with the multi finger rodot hands are playing an important role in the field of manufacturing, rehabilitation and other applications that require precision and dexterity[1].Dexterous grasping is the specific task and it has been accepted and adopted by many researchers as apriority issue while designing the hands. The essential modifications related to the robotic grippers such as improved force sensing capacity and improved flexibilities at the gripping are to be implemented.The multi-fingered robot hand acts as a multipurpose gripping device for various tasks with multiple-degrees-of-freedom. Some important multi-fingered hands are, WENDY hand [2], Utah/MIT hand [3], DLR hand [4], Shadow Dexterous Hand [5], Robonaut hand[6]. Such type of hand has advantage that the hand can be used with various type of robot arms because the robot hand has independant structure. Most of this type of robot hand has equal or less than four fingers. Even those with five fingers are not equal with human hand because they have less number of joints or degrees of freedom.The robot hands with five fingers and anthropometric structure are helpful for the patients who are partially paralyzed due to neurological or orthopedic impairment. The need for improving the muli-fingered robot hand arises from the desire forhandling objects of complicated shapes effectively.Therefore the mechanical design plays an importtant role in the development of the present hand.In this paper we only concentrate on the kinematic analysis of the anthropomorpphic robot hand and consider the wrist as a fixed. The hand is an articulated structure. All fingers in the model have the same essential structure, having different degrees of freedom,so the same convention is applied to all fingers. The fixed coordinate system with respect to which the whole motion is analyzed is placed outside of the hand's areai.e. at wrist. DoFs in CMC area is different with thumb having two DoFs, the ring and little fingers have two DoFs and index and middle fingers have no motion. The skeleton of a hand is abstracted as a stick figure so that the dimension of each sub-object is reduced to its link length. Each finger is modeled as a kinematical chain with the palm as its base reference frame. The model does not consider the radio carpal articulation (wrist). Each fingertip is considered to be the end-effecter of the respective finger kinematical chain.The aim of the present study is to obtain a kinematic model of the anthrpomorphic robot hand, as natural as possible and to make it capable of realizing various tasks in 3D environment. The analysis of the forward kinematics of the proposed model is studied by representing the active space as a complex surface (reach envelope) with respect to wrist.

Kinematic Model of Anthropomorphic Robot Hand

The multi-fingered robot hand acts as a multipurpose gripping device for various tasks. Since it is designed to mimic the human hands, most anthropomorphic robot hands duplicate the shape and functions of human hands. The structure of the anthropomorphic hands is almost the same as that of a human hand as shown in Fig. 1. The finger segments in human hand gives us the inspiration to design an independently driven finger segment to construct a whole finger. The segmental lengths of the thumb and fingers are taken proportionately to hand length and hand breadth with a fixed wrist.Typically the hand motion is approximated to have 27 DoFs.In thepresent study only 25 DoFs are considered. The thumb is modeled with 5 DoFs.The index and middle fingers are modeled with 4 DoFs each. The ring and little fingers are modeled with 6 DoFs each considering two degrees of freedom each at Carpometacarpel(CMC) joint for palm arch. The Trapeziometacarpal (TM) joint, all five Mecapophalangeal (MCP) joints and two CMC jointsare considered with two rotational axes each for both abduction-adduction and flexion-extension. The Interphalangeal (IP) joint on the thumb, the Proximal-Interphalangeal (PIP) and Distal- Interphalangeal (DIP) joints on the other four fingers possess 1 DoF each for the flexion-extension rotational axes. Fig.1 illustrates the proposed hand model while the parameters of the thumb and other fingers are tabulated in Table 4 and Table 5 respectively.

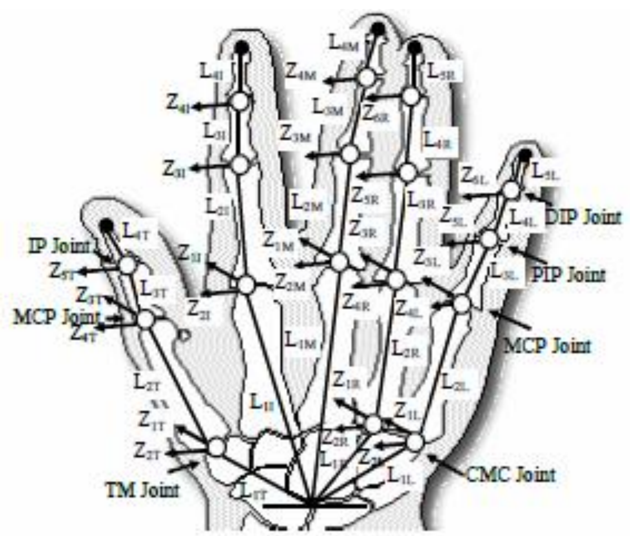

Fig.1 Kinematic model of hand

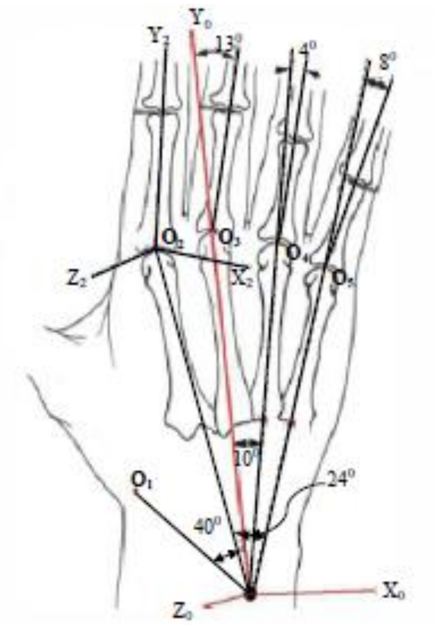

Fig.2 Global co-ordinate system

Table 1 DH table of thumb

Link(i)	Link twist angle(α_{i-1})	Link length(a_{i-1})	Joint Distance(d_i)	Joint angle(θ_i)
1T	0^0	L_{1T}	0	θ_{1T}
2T	-90^0	0	0	θ_{2T}
3T	90^0	L_{2T}	0	θ_{3T}
4T	-90^0	0	0	θ_{4T}
5T	0^0	L_{3T}	0	θ_{5T}
ε_T	0^0	L_{4T}	0	0

Table 2 DH table of index and middle fingers

Link(i)	Link twist angle(α_{i-1})	Link length(a_{i-1})	Joint distance(d_i)	Joint angle(θ_i)
1F	0^0	L_{1F}	0	θ_{1F}
2F	-90^0	0	0	θ_{2F}
3F	0^0	L_{2F}	0	θ_{3F}
4F	0^0	L_{3F}	0	θ_{4F}
ε_F	0^0	L_{5F}	0	0

Table 3 DH table of ring and little fingers

Link(i)	Link twist angle(α_{i-1})	Link length(a_{i-1})	Joint Distance(d_i)	Joint angle (θ_i)
1F	0^0	L_{1F}	0	θ_{1F}
2F	-90^0	0	0	θ_{2F}
3F	90^0	L_{2F}	0	θ_{3F}
4F	-90^0	0	0	θ_{4F}
5F	0^0	L_{3F}	0	θ_{5F}
6F	0^0	L_{4F}	0	θ_{6F}
ε_F	0^0	L_{5F}	0	0

Anthropometric Data and Joint Limits. As there were no exact anthropometric data for the segmental lengths of the human hand, the estimated measurement are made following standard formulae, where HL is Hand Length and HB is Hand Breadth[7] similarly the angle limits for different joints considered from work of Parsuramna and Zuen[8] .

Table 4 Segment Length for Thumb

Finger	Metacarpal bones	Length
Thumb	$0.251*HL$	L_{2T}
Index	$\sqrt{(0.374 * HL)^2 + (0.126 * HB)^2}$	L_{2I}
Middle	$0.373*HL$	L_{2M}
Ring	$\sqrt{(0.336 * HL)^2 + (0.077 * HB)^2}$	L_{2R}
Little	$\sqrt{(0.295 * HL)^2 + (0.179 * HB)^2}$	L_{2L}

Table 5 Segment length for fingers

Fingers	Proximal	Length	Middle	Length	Distal	Length
Thumb	$0.196*HL$	L_{3T}	-	-	$0.158*HL$	L_{4T}
Index	$0.265*HL$	L_{3I}	$0.143*HL$	L_{4I}	$0.097*HL$	L_{5I}
Middle	$0.277*HL$	L_{3M}	$0.170*HL$	L_{4M}	$0.108*HL$	L_{5M}
Ring	$0.259*HL$	L_{3R}	$0.165*HL$	L_{4R}	$0.107*HL$	L_{5R}
Little	$0.206*HL$	L_{3L}	$0.117*HL$	L_{4L}	$0.093*HL$	L_{5L}

Kinematics Analysis. Forward kinematics is used to determine the position and orientation of the proposed hand model with respect to fixed point i.e. wrist. For this purpose a kinematic model is developed using the given joint angles, the fingertip position in the palm frame is calculated with respect to MCP joints of Middle and Index finger, TM joint of thumb and CMC joint of ring and little finger. The origins are located at the respective joints marked as O_1, O_2, O_3 ,O_4 and O_5 as shown in Fig. 2.The DH method is implemented to determine the DH parameters for all the fingers which are tabulated in Table 1, Table 2 and Table 3. The global coordinate system for hand is located in the wrist as shown in Fig.2. The transfer from a reference frame to the next one the general expression of the matrix can be written as follows:

$$^{i-1}T_i = \begin{bmatrix} \cos q_i & -\sin q_i \cos\alpha_i & \sin q_i \sin\alpha_i & L_i \cos q_i \\ \sin q_i & \cos q_i \cos\alpha_i & -\cos q_i \sin\alpha_i & L_i \sin q_i \\ 0 & \sin\alpha_i & \cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

$$^{0}T_n = {}^{0}T_1\, {}^{1}T_2\, {}^{2}T_3 \cdots\cdots\cdots {}^{n-1}T_n \quad (2)$$

By multiplying the corresponding transfer matrices written for every finger as in Eq. 2, the kinematical equations describing the fingertip motion with respect to the general coordinate system can be determined. It is now possible to develop a model using Eq.1 and Eq.2. A computer program using these equations in MATLAB is developed to capture the motion of the fingers. Every joint variable range as per data is divided to an appropriate number of intervals in order to have enough fingertips positions to give confident images about the spatial trajectories of these points. By connecting these positions and the complex surface bordering the active hand model workspace is obtained. The complex surface could be used to verify the model correctness from the motion point of view, and to plan the hand motion by avoiding the collisions between its active workspace and obstacles in the neighborhood.

Results

Using the Eq.1and Eq.2 along with the parametric data of human fingers presented in Table 4 and Table 5 the complex surface described by each finger tip is generated. In all the cases each angular range is divided into equal divisions. The profiles generated through the simulation of the independent finger tips are spatial. The different colour specifies for different fingers i.e. red for thumb, blue for Index finger, magenta for middle finger, green for ring finger and black for little finger. However, for the purpose of understanding and simplicity, these are presented in X-Y, X-Z and Y-Z planes in Fig. 3, Fig. 4 and Fig. 5 respectively. The profiles of the five finger tips in the 3-D plane are presented in Fig.6.

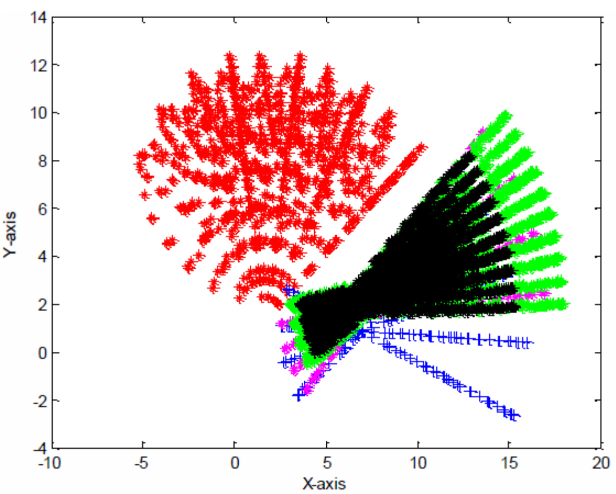

Fig. 3 Profile of fingertips in the X-Y plane

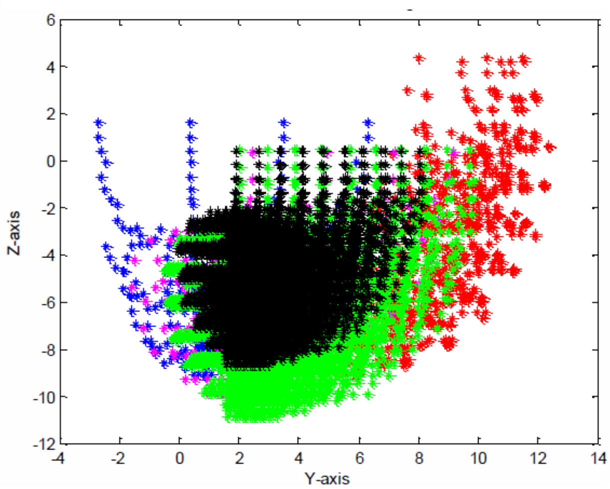

Fig. 4 Profile of fingertips in the Y-Z plane

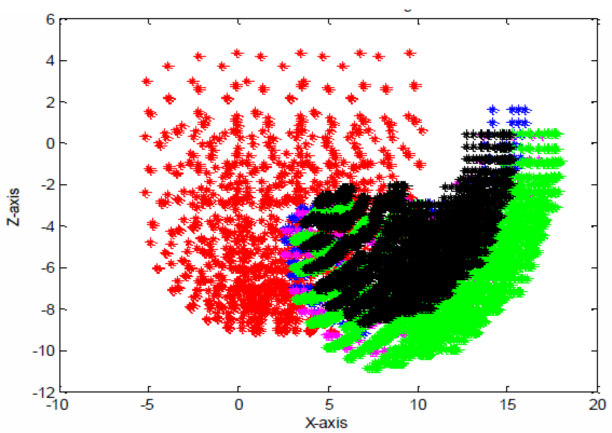

Fig. 5 Profile of fingertips in the X-Z plane

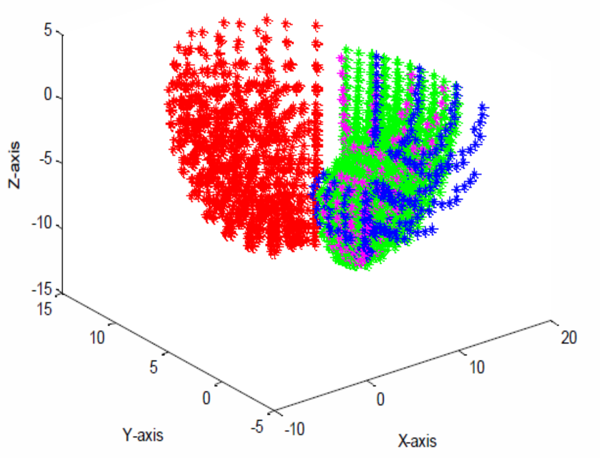

Fig. 6 Profile of fingertips in the 3-D space

Conclusion

The present work aims at developing a kinematic model of an anthropomorphic robot hand and assessing it effectiveness. The hand in question may find its potential applications in industries and other work places for manipulation of irregular as well as soft objects. It can also be used for orthopaedic rehabilitation of human hands. The model considers five fingers similar to human hand for manipulating objects securely. The joints, links and other kinematic parameters are chosen in such a way that they replicate a human hand. The kinematic simulation is carried out to estimate the work volume and assess motion constraints of the designed hand. The study shows that the kinematic behavior of the hand is suitable for the intended purpose.

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